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AN OBSERVATION OF THE LYMAN-BIRGE-HOPFIELD SYSTEM IN AN AURORA

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FOREWORD

This report is a manuscript of a paper which has been submitted for publication in the Journal of Geophysical Research. The auroral experiment described herein is one of a continuing series conducted by our laboratory.

G. H. Dieke
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The Lyman-Birge-Hopfield bands of N_2 have been observed at 2A resolution in an aurora. Accurate measurements of intensities were not possible because of rocket malfunctions, but the intensity of any relatively strong band appeared to range from about 0.5 to 5 kr when the 3914 A band of N_2^+ was between 25 and 150 kr.

Author

INTRODUCTION

The results of a low resolution (17A) survey of the auroral spectrum from 1100 A to 3500 A have been reported by Crosswhite, Zipf, and Fastie (1962). They tentatively identified certain features with the $\Delta v = 6$ to $\Delta v = 9$ sequences of the Lyman-Birge-Hopfield system of $N_2(a^1\pi_g \rightarrow X^3\Sigma_g^+)$. The identification could not be considered definite since several bands of the Vegard-Kaplan system lie in the same spectral region, and there are band heads in both systems which lie close to the intensity peaks observed in their experiment. (See Table I.)

The present experiment was designed to provide more definitive results concerning the identification of the LBH system by scanning the region from 1410 A to 2210 A at 2A resolution so that the individual bands of a given sequence could be distinguished.

INSTRUMENTATION

The spectroscopic instrumentation was similar to that described for previous rocket experiments (Fastie 1963). An Ebert spectrophotometer, using an EMR 543F photomultiplier tube as a detector, was employed for scanning the spectral region of interest. The relative spectral sensitivity of the photomultiplier was obtained by comparing its response at several wavelengths to that of a photomultiplier tube having a window coated with sodium-salycilate which was assumed to have a uniform quantum efficiency. The transmission of the optical system, i.e. mirror and grating, was measured at several wavelengths from the relative value of the incident and transmitted intensities of a beam of essentially monochromatic light. The uncertainty of the relative intensity calibration for the whole detection system was estimated to be approximately $\pm$ 20%.

A value for the absolute sensitivity of the instruments, with an uncertainty of about 50%, was obtained at 2537 A using a calibrated mercury arc lamp as a standard. The response of the detection system was adjusted for full scale readings of 2.5 kr and 25 kr on the two telemetering channels that transmitted the photomultiplier signals; the smallest measured signal was about 0.50 kr, a limit set by abnormally high noise which developed during the flight.

The 3914 A (0,0) first negative band of N_2^+ was monitored continuously by a photometer that was set to produce a full scale reading of 25 kr. The photometer was baffled to accept light passing through a cone of 5×10^{-2} steradians and the transmission function of the filter employed had a full-width at half maximum of 40 A.

EXPERIMENT

An Aerobee rocket, launched on 26 February, 1964, from Fort Churchill, Canada, carried the instruments. The initial stages of the flight proceeded in a satisfactory manner but at approximately 30 km, 20 seconds before the nose cone tip was ejected, an instability developed which caused the rocket to yaw in a 170^0 cone. The orientation of the precessing axis of the cone varied from 3^0 to 13^0 to the zenith. This motion persisted throughout the flight with a yaw period of 2.5 seconds. The maximum altitude attained was 170 km.

A partial record of the photometer output during the ascent is shown in Fig. 1. Signals from two different sources, denoted by A and B, were apparent immediately after ejection

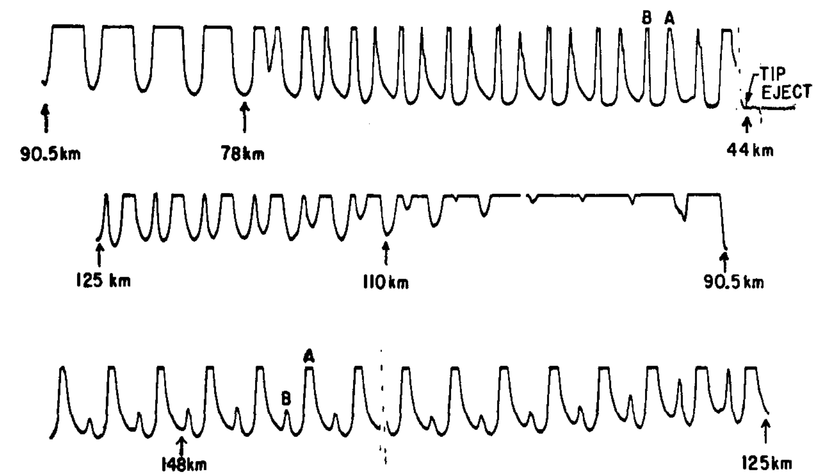

Fig. 1 Photometer signal of (0, 0) N_2^+ band during rocket ascent.

of the nose cone. Signal A did not vary much in shape nor amplitude below 70 km and above 130 km, whereas the maximum intensity of signal B was larger than 25 kr below 70 km but only about 2 kr above 130 km. In the intervening region where the rocket passed through the center of the aurora the amplifiers were saturated and the two distinct signals were not evident. The source of signal A appeared to be a reflection from the earth or horizon light because it was almost constant in shape and amplitude for all altitudes of the rocket. Signal B, which became much weaker at high altitudes was probably due to auroral light. Below 70 km, the spectrometer was pointed up through the aurora (although not vertically) once every 2.50 seconds then back toward the horizon or the earth 1.25 seconds later; the signal intensity became zero between these two positions. At the rocket passed through the aurora, light from the 3914 A band entered the photometer no matter what its orientation. From 70 km to 130 km the signal from source B decreased then maintained a constant small value because the rocket was above the main body of the aurora.

As a result of the rocket rotation the effective source of the ultra-violet light varied quite rapidly and the relative intensities of observed bands were not representative of those that would have been measured had the rocket been pointed in a constant direction.

Large random noise pulses of undetermined origin appeared on the spectrometer channel shortly before ejection of the nose cone tip and were seen throughout the experiment. Many weaker spectral features were obscured by this interference and even intense bands that were closely spaced were sometimes difficult to resolve. In Fig. 2 which illustrates some of the better experimental results, these noise pulses are seen to be quite prominant. Nevertheless, most of the outstanding spectral features could be identified.

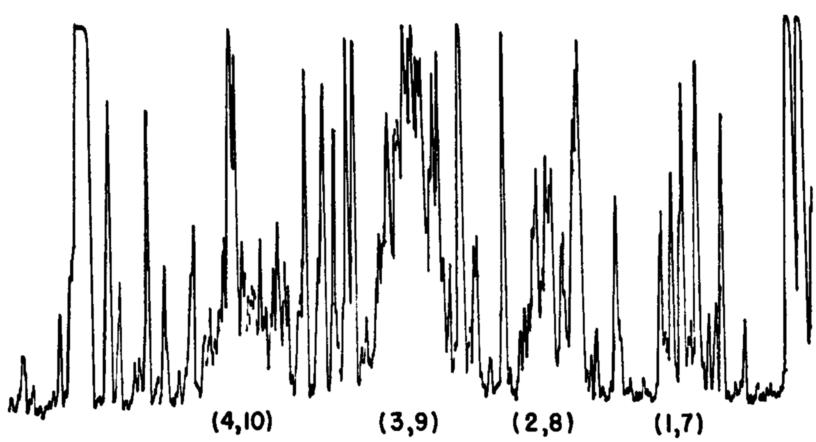

Fig. 2 A segment of the $\Delta v = 6$ sequence of the LBH system.

An indication of the height profile of the aurora was obtained by plotting the minima of the 3914 A signal observed during each rotation; i.e., when the rocket was oriented almost horizontally. This profile is shown in Fig. 3. The lower boundary was well defined around 92 km, and the maximum intensity occurred at about 100 km. Ground based observations indicated a type II aurora in which the average intensity of the 5577 A OI line was about 15 kr.

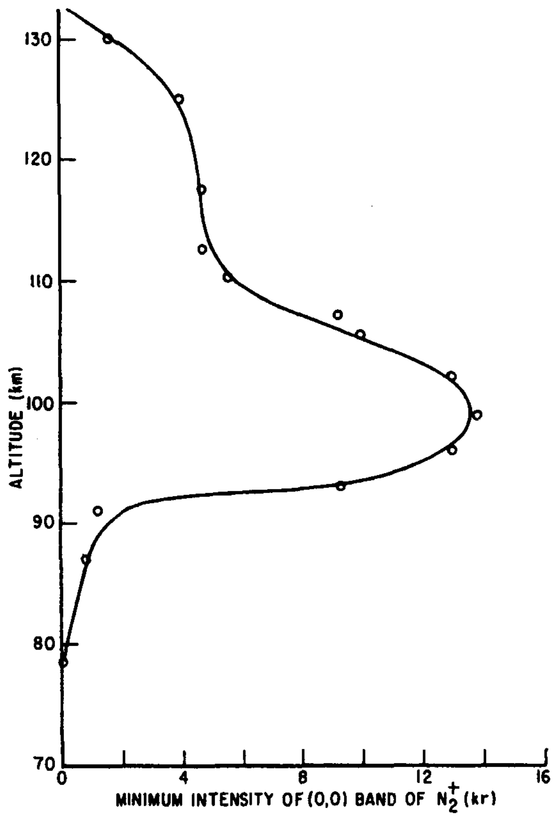

Fig. 3. Altitude profile of aurora.

RESULTS

Uncertainties in the determination of the wavelengths arose from variations in the speed of the scanning motor, small irregularities in the surface of the cam which controlled the rotation of the grating, variations of intensity caused by the rotation of the rocket, and photomultiplier noise. Differences between band heads could be established only to an accuracy of 3 or 4 A. Within these limits all the clearly discernable bands could be assigned to the LBH system; however, it remained possible that about half the bands may have been blended with the VK system. No bands were found in the preliminary data reduction that could be attributed solely to the VK system. The atomic nitrogen lines around 1744 A were not detected nor was there any apparent emission from molecular oxygen or nitric oxide. All the LBH bands which lie within the spectral region that was scanned are listed in Table II together with the average intensity of the bands actually detected. These averages were computed from no more than six observations on any given band. Unresolved blends are denoted by brackets and the intensity listed is due to both components.

The relative theoretical intensities expected among the various LBH bands were calculated in order to support their identifications from the experimental data. It was assumed that collisional excitation and radiative de-excitation were the most important factors in determing the populations of the different vibrational levels of the $a^1\pi_g$ state, because its natural lifetime, 1.7×10^{-4} sec (Lichten, 1956), is much smaller than the time between collisions which could quench the excitation.

The detailed balance equation involving the population of a given vibrational level, v' is (Bates 1949)

$$\sum_{v''} N_{v''} \; P(v''v') \int K(\epsilon) f_\epsilon \; d\epsilon = \sum_{v''} A_{v'v''} N_{v'} \qquad (1)$$

where $N_{v''}$ is the concentration of molecules in a given vibrational level of the ground electronic state and $A_{v'v''}$ is the rate per molecule of spontaneous transitions between two vibrational levels. $K(\epsilon)$ is proportional to the square of the multipole moment, $P(v''v')$ is the Franck-Condon factor (Nicholls 1961), and f_ϵ is the distribution function for electron energies. The intensity emitted in a given transition is

$$I_{v'v''} = h\nu_{v'v''} A_{v'v''} N_{v'} \qquad (2)$$

$N_{v'}$ is given by (1) so the intensity may be written as

$$I_{v'v''} = \frac{h\nu_{v'v''} \; A_{v'v''} \; \sum_{v''} N_{v''} \; P(v''v') \int K(\epsilon) f_\epsilon \; d\epsilon}{\sum_{v''} A_{v'v''}} \qquad (3)$$

Because the computed intensities were to be compared with experimental values in which there were large uncertainties, the electronic transition moment between any two vibrational levels was assumed to be the same. In addition, the term $\Sigma_{v''} A_{v'v''}$ varies by only about 12% for all the progressions considered here (v' = 1 to v' = 6) and was taken to be constant. $N_{v''}$ can be neglected for all v"> 0, and $A_{v'v''}$ is proportional to p(v'v") so that the relative intensity of two bands is given by

$$\frac{I_{v_1' v_1''}}{I_{v_2' v_2''}} = \frac{\nu^4_{v_1' v_1''} \quad P(v_1' \; v_1'') \; P(0, v_1')}{\nu^4_{v_2' v_2''} \quad P(v_2' \; v_2'') \; P(0, v_2')} \tag{4}$$

The relative intensities computed from (4) are shown in Table II normalized to the intensities of the (3, 9) band. Correlation between experimental and theoretical numbers is within factors of two or three. Bands that were computed to be relatively weak compared to the (3, 9) band (less than 0.1) were not observed and all those calculated to be relatively strong except (4, 9) were actually detected, at least for wavelengths greater than 1700 A where absorption by molecular oxygen was unimportant. In general, the calculated values support the assignment of all the observed spectral lines to the LBH system.

The LBH bands appeared only when the signal from the (0, 0) first negative band of N_2^+ saturated the amplifiers so that a direct comparison of intensities is not available. The lower limit on the 3914 A intensity is 25 kr for all the observed bands shown by Table II, and rough reconstructions of the off-scale portions of the photometer signals from the slopes of the patterns illustrated by Fig. 1 indicate that an upper limit should be about 150 kr. Therefore, as a crude approximation, the intensities listed in Table II can be considered as representative of an aurora in which the 3914 A band intensity is about 90 kr.

ACKNOWLEDGMENTS

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TABLE I

Intensity Maxima Observed by Crosswhite, et al, (1964) and Wavelengths of Nearby Band Heads of N_2 (Wallace, 1962).

Observed Intensity Maxima (Å)	VK Band Head (Å)	LBH Band Head (Å)
1850	1853 (3, 0)	1845 (3, 9)
1933	1936 (3, 1)	1928 (3, 10)
2035	2046 (1, 1)	2042 (5, 13)
2145	2147 (1, 2)	2145 (6, 15)

TABLE II

OBSERVED INTENSITIES OF LBH BANDS

Asterisk denotes that VK band head lies within 5 Å of LBH head.

λ	Band	Average Measured Intensity (kr)	Calculated Intensity Relative to (3, 9) band
1412	4, 2	---	1.24
1416	1.0	---	1.06
1426	5, 3	---	0.64
1430	2, 1	---	1.24
1441	6, 4	---	0.02
1444	3, 2	---	1.01
1450	0, 0	---	0.14
1459	4, 3	---	< .01
1464	1, 1	---	1.57
1473	5, 4	---	0.92
1479	2, 2	---	0.04
1489	6, 5	---	0.43
1493	3, 3	---	0.84
1501	0, 1	---	0.42
1508	4, 4	---	0.79
1515	1, 2	---	0.59
1523	5, 5	---	0.11
1530	2, 3	1.63	1.13
1539	6, 6	---	0.43
1545	3, 4	---	0.14
1555	0, 2	---	0.63
1560	4, 5	---	0.34
1569	1, 3	---	< .01
1576	5, 6	---	0.98
1584	2, 4	0.54	0.81
1591	6, 7	---	0.21
1600	3, 5	---	0.95
1611	0, 3	---	0.57
1615	4, 6	---	0.14
1627	1, 4	---	0.52
1631	5, 7	---	0.10
1642	2, 5	---	< 0.01
1647	6, 8	---	< 0.01
1658	3, 6	---	0.59
1672	0, 4	---	0.34
1674	4, 7	---	0.72
1687*	1, 5	1.07	0.98
1690	5, 8	---	0.26
1703	2, 6	---	0.48

λ	Band	Average Measured Intensity (kr)	Calculated Intensity Relative to (3,9) band
1706	6,9	---	0.27
1719	3,7	---	< 0.01
1735	4,8	1.15	0.24
1736	0,5		0.15
1752	5,9	1.41	0.42
1752	1,6		0.83
1768*	2,7	1.35	1.11
1769	6,10		0.27
1784	3,8	0.91	0.56
1801	4,9	---	0.58
1805	0,6	---	0.06
1818	5,10	1.15	0.35
1821	1,7	1.07	0.43
1835*	6,11	2.17	0.15
1837	2,8		0.97
1854*	3,9	3.93	1.00
1871*	4,10	0.90	0.76
1878	0,7	---	0.02
1888	5,11	---	0.15
1894	1,8	0.64	0.16
1905*	6,12	---	< .01
1911	2,9	1.06	0.50
1928*	3,10	1.29	0.80
1945	4,11	1.27	0.49
1956	0,8	---	< .01
1962	5,12	0.93	0.49
1973	1,9	---	.04
1980	6,13	0.96	0.19
1990*	2,10	1.11	0.17
2007*	3,11	1.05	0.37
2024*	4,12	0.64	0.48
2042*	5,13	1.18	0.49
2057	1,10	---	< .01
2060*	6,14	0.93	0.32
2073	2,11	---	0.04
2091	3,12	0.76	0.12
2109*	4,13	0.87	0.20
2127*	5,14	0.93	0.31
2145*	6,15	0.79	0.22
2181	3,13	---	0.02
2199	4,14	---	0.08

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